

## **16. The effect of soil and water conservation treatments on rainfall-runoff response and soil losses in the Northern Ethiopian Highlands: the case of May Leiba catchment**

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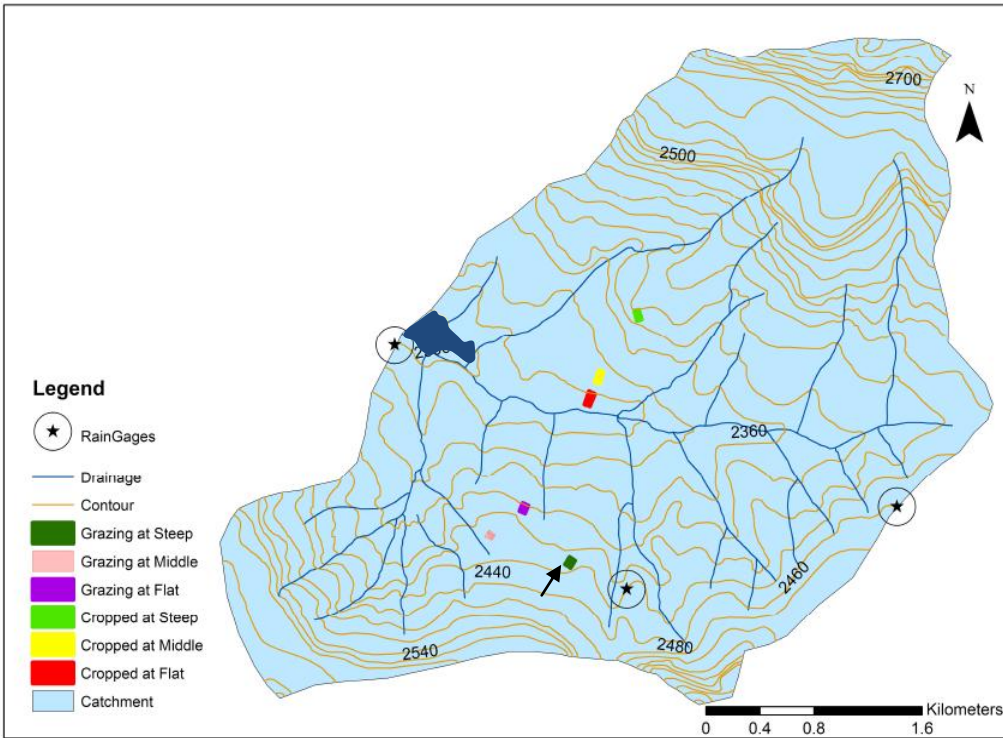
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### **1. Introduction**

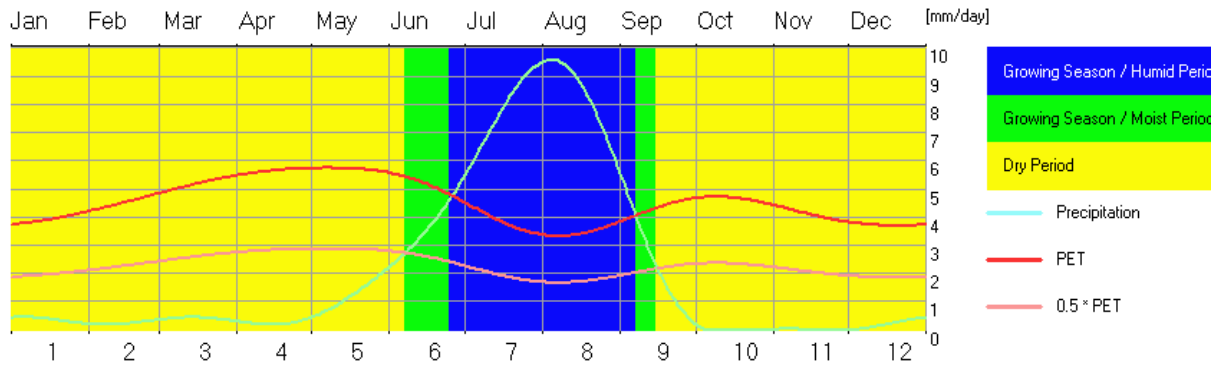
In Tigray region, an attempt has been made at different levels to reduce the effect of moisture stress on agricultural productivity through water harvesting, and 54 earth dams were constructed from 1994 to 2003. Haregeweyn et al., (2006) emphasized that the most important challenges related to water harvesting schemes are siltation, and less water storage in the reservoirs compared to design capacity. Losses due to seepage, evaporation and to physical soil and water conservation (SWC) structures in the catchment are not well documented. In the same study differences of inflow were also observed between years before and after treating catchments with SWC structures attempting to reduce sediment inflow into the reservoirs. In the first three years the inflow was high in some reservoirs but with the construction of SWC structures, the runoff volume delivered decreased. This already indicates that the impact of SWC structures on the hydrological responses of the catchments has been overlooked during the planning and designing phases of most water harvesting structures in Tigray. Understanding the effect of SWC treatment on hydrological responses is crucial for proper design of water harvesting schemes and to resolve conflict of interest arising between treating catchment with different SWC measures and collecting water in the reservoir for irrigation. The overall objective of this study is therefore, to better understand runoff generation processes in areas treated with different SWC measures and thereby, to contribute to better water resources management for local communities in semi-arid highlands of Ethiopia. More specific objectives include: 1. quantify the effect of different SWC treatments on rainfall-runoff response at plot scale 2. Identify the major factors and their relative importance in controlling the transformation of rainfall to runoff within plots. 3. Determine the effect of SWC measures on soil loss reduction for different land use and slope.

### **2. Description of the Study Area**

The May Leiba catchment and its major geological and geomorphic features are described by Van de Wauw et al. (2008) and on p. 72 in this excursion guide. More than 80% of rainfall at May Leiba is concentrated and occurs between June and September (Nyssen et al., 2005), preceded by more dispersed rain during March to May. The region is characterised by recurrent drought and extreme moisture stress which during some years results in crop failure due to very short growing period (Fig.2). The average monthly air temperature ranges between 12 and 19 °C. Cropland is the major land use in the catchment covering around 65% of the area and other land uses include rangeland for grazing, residential areas and exclosures.



*Figure 1. Study catchment with the location of runoff and rainfall measuring sites. Arrow indicates the visited plot*

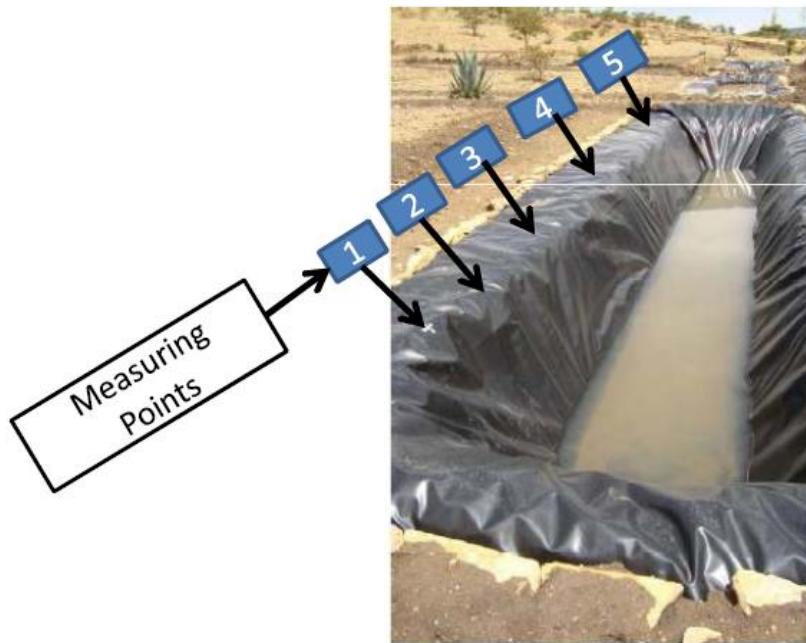


*Figure 2. Long-term averages from FAO's «New LocClim» tool.*

### 3. Methodology

Field-sized runoff plots on rangeland (600-630 m<sup>2</sup>) and on cropland (770-1000 m<sup>2</sup>) were installed in February to April 2010 before the rainy season. These plots were located on three slope ranges; gentle, middle and steep slopes of the rangelands and croplands. Measuring sites on the rangelands had three SWC treatments (stone bund, trench and stone bund with trench) plus one control plot; while those on croplands had two SWC treatments (stone bund and stone bund with trench) and one control for each site. All plots were bounded with soil bunds (50cm wide 30-45cm high). Run-on interception ditches were installed to protect the plots from inflow. The plots were kept 3 m apart to avoid interflow of water from one plot to the next and lined with geomembrane plastic to store the runoff generated from each plot.

The depth of water in the trench is measured and water is removed manually on a daily basis. The runoff collecting trenches were designed to accommodate runoff resulting from extreme rainfall events using the maximum rainfall recorded from 2004 to 2006, and maximum runoff coefficient. Runoff volume was calculated from runoff depth measurements using depth-area relationship, subtracting the direct rain falling on the trench. To compensate for trench geometry, runoff depth measurements were taken at five fixed points along the trench (Fig. 3).



*Figure 3. Water collecting trench at the foot of a runoff plot and measuring points for water depth*

Ground cover by vegetation was monitored on a weekly basis using point count method at 50 cm interval during the rainy season. Runoff samples were collected to determine sediment concentration after thoroughly mixing the water in the collector trench using floor brush. The samples were filtered using Whatman no. 42 filter paper. The sediment was oven dried at 105°C for 24 hours and weighed and then soil loss was calculated and expressed in tons/ha/yr. The runoff depth for each plot was calculated by dividing runoff volume by the plot area.

One way ANOVA has been used to test effects of SWC treatments on runoff response. Two ways ANOVA were also used to see the effects of SWC treatments against land use and slope. Statistically significant means were separated using Tukey LSD family wise 95% confidence interval.

## **4. Results and discussion**

### **4.1. Effect of SWC treatments on plot runoff**

The runoff plots at every site were similar in all biophysical characteristics (i.e. slope gradient and aspect, land use, soil type and geology) and showed significantly different ( $p < 0.000$ ) runoff responses due to type of SWC structures. Runoff response was the highest for the control plots at all sites (Fig. 4).

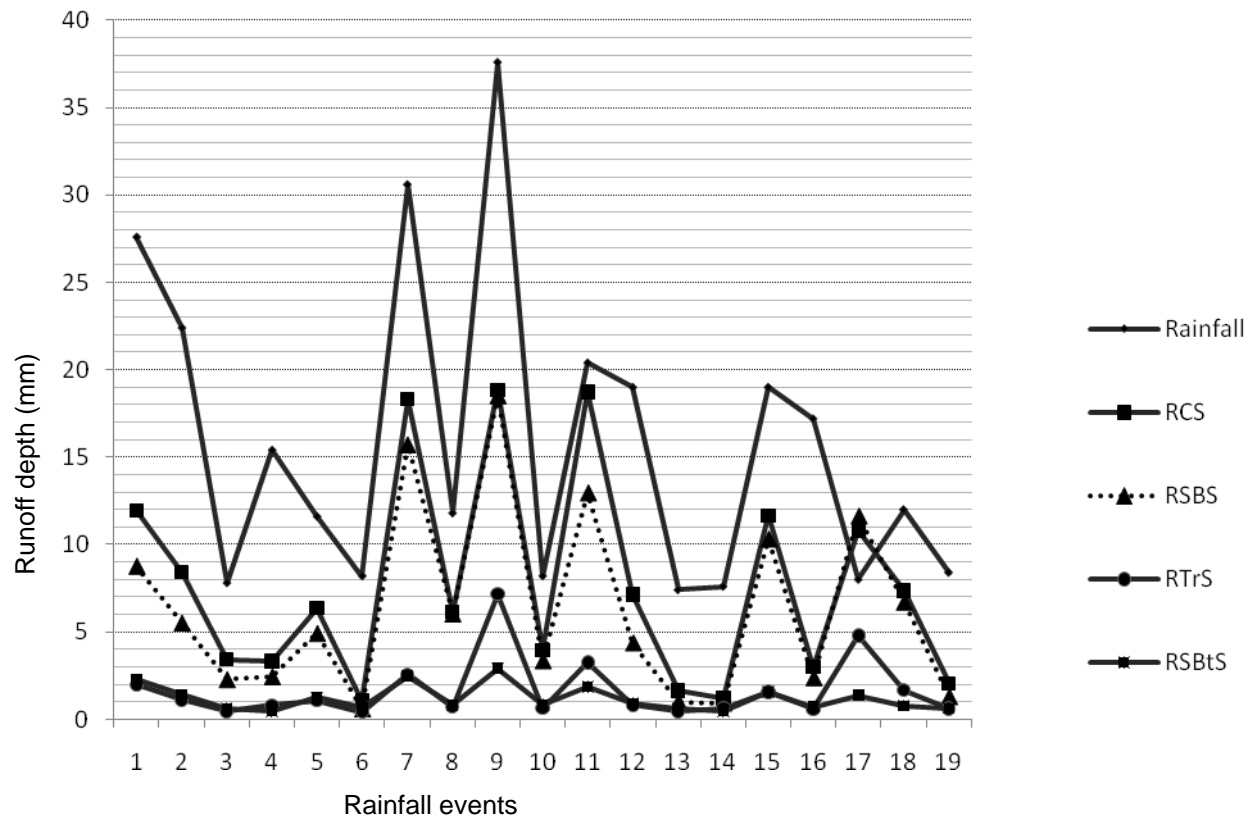


Figure 4. Runoff to rainfall relationship for the different SWC treatments on the experimental plot on rangeland with steep slope (RCS control, RSBS stone bund, RTrS trench, RSBtS stone bund with trench).

The runoff responses for different SWC treatments follow the rainfall trend however; specific runoff response also depends of the rainfall characteristics. Different depths of rains can produce a similar amount of runoff, if intensity or antecedent soil moisture conditions are different. This is clearly indicated by events 7, 9, and 11 (Fig. 4). Runoff depth is correlated with rainfall depth ( $R^2 = 0.64$ ). During all observed rainfall events the runoff reduction effect of trenches and stone bund with trench is very strong (Fig. 5) at the beginning of the rainfall season. However, during the rainy season storage capacity of the trench progressively decreased due to sediment accumulation in the trench and erosion of the soil bund downslope of the trench. It seems that they also have similar runoff response for smaller rainfall event but when storage capacity of trench is exceeded plot runoff response also increases. Compared to the control plot average runoff reductions were 85%, 62% and 17% for stone bund with trench, trench and stone bund respectively on rangelands. On cropland, runoff reduction effects were less, only 11% and 61% reduction was observed for stone bund and stone bund with trench respectively. Less runoff reduction effect of SWC treatments on cropland compared to rangeland may be due to the additional effects of crop cover, soil management and other agronomic practices. Runoff reduction of 40-50% on intensively cultivated cropland treated with bunds was reported earlier (Hurni et al., 2005). Nyssen et al., (2010) also reported that reemerging springs at the foot slopes of treated catchments and rise in groundwater table are related to the introduction of SWC structures.

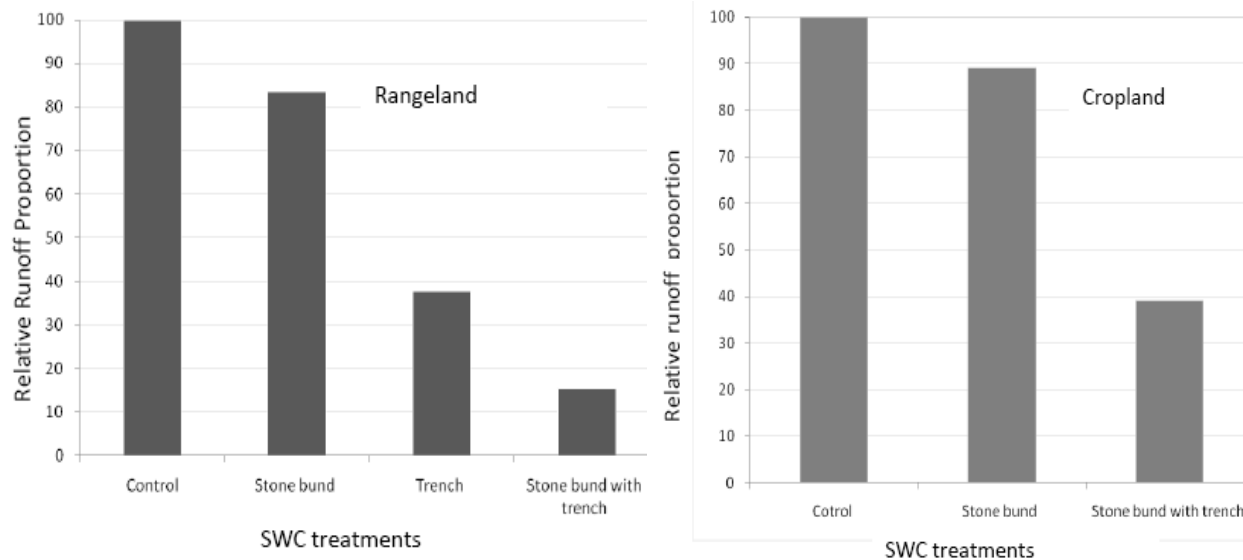


Figure 5. Relative runoff proportion for different SWC treatments compared to control ( $n = 3$ )

#### 4.2. Effect of slope gradient on runoff responses

Slope is an important topographic variable affecting soil erosion rate and catchment runoff responses. However, the effect of slope in this study remains insignificant ( $p = 0.62$ ) to explain runoff variability among SWC treatments. Besides unaccounted spatial rainfall variability, this is attributed to local differences in soil infiltration rate as influenced by parent material, rock fragment cover and soil type. Runoff depth from the gentle slopes was even higher than from steep and moderate slopes because of the vertic nature of the soil which affects the rate of infiltration once the top layer is saturated. Descheemaeker et al. (2006) have shown that runoff in Tigray, even in areas with restoring vegetation, is mainly Hortonian. Runoff response to rainfall occurs before the soil gets saturated. The influence of rock fragment cover which dramatically increases with slope gradient in the study area is another reason; the negative relationship between runoff depth and rock fragment cover is well documented (de Figueiredo and Poesen, 1998).

#### 4.3. Effect of land use on plot runoff responses

Land use effect on plot runoff response was very significant ( $p < 0.000$ ). Runoff response is higher for rangeland as compared to cropland (Fig. 6). This is probably due to soil cultivation during the beginning of the rainy season and increased vegetation cover later during the rainy season on cropland in contrast with reduced infiltration, increased runoff and soil erosion on rangeland (Stroosnijder, 1996; Mwendera and Mohamed, 1997).

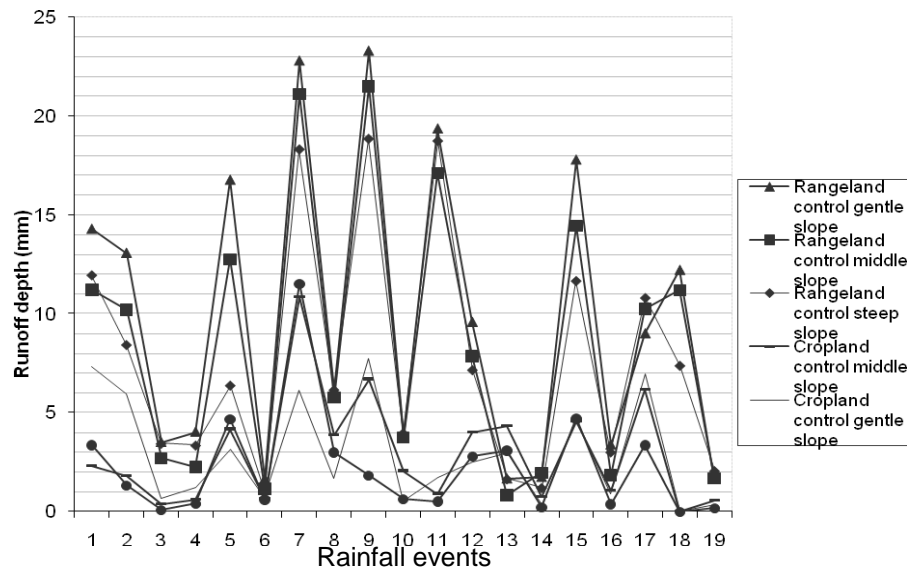


Figure 6. Effect of land use on runoff response

#### 4.4. Effect of SWC treatments on soil loss

Particularly on steep slopes, soil loss is much lower on cropland compared to rangeland (fig. 7) probably due to a larger vegetation cover during the rainy season. The amount of soil loss from plots is different for different due to SWC treatment (Fig. 7). The soil loss from the control plot is always higher for all land uses, slope categories and regardless of the type of crops grown. The soil loss reduction of stone bund in this study was 69% for rangeland. On cropland soil loss reduction due to stone bund was 89% which is attributed to the combined effect of vegetation cover and soil management on cropland. Soil loss reduction due to stone bund with trench and trench were even more.

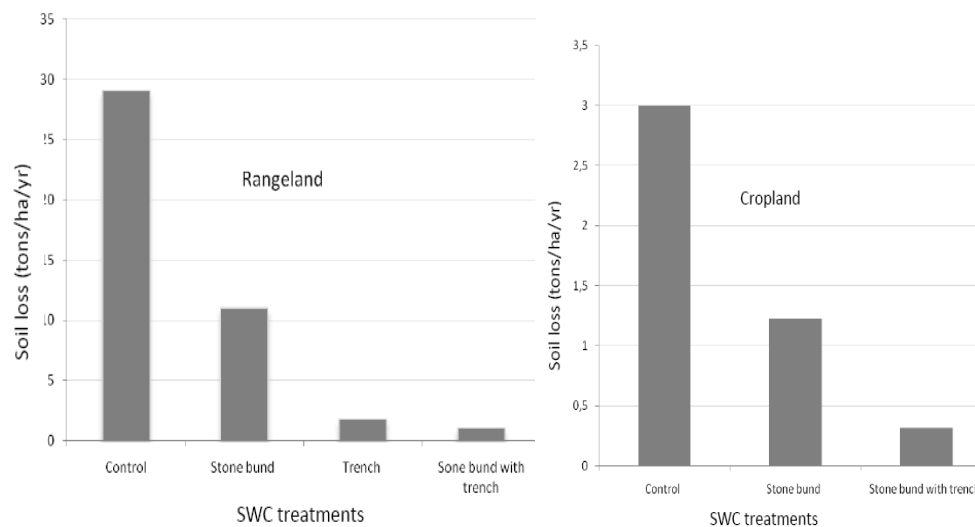


Figure 7. Effects of SWC treatments and land use on soil loss on steep slopes

## 5. Conclusions

Introduction of SWC structures may highly reduce the runoff delivered to storage structures such as ponds and reservoirs. Introduction of stone bund with trench, trench and stone bund led to runoff reduction by 85%, 62% and 17% respectively for rangelands. The effect of SWC structures on runoff responses is highly influenced by land use while the effect of slope gradient is negligible. On average, the introduction of stone bunds can reduce soil loss by 68%; this effect will significantly reduce sediment load to the reservoirs while runoff reduction is less. Therefore massive construction of stone bund would be recommended because of high runoff response and significant soil loss reduction. There should be optimum level of SWC intensity so as to let some surface flowing to the reservoir while significantly reducing sediment load; in this regard trenches and stone bunds with trenches should be used only in parts of the catchment where complete in situ conservation of water is desired.

## References

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